STUDY ON COST-BENEFIT ASSESSMENT PROCEDURE FOR ROAD DISASTER PREVENTION PROJECTS

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ABSTRACT

Large-scale earthquakes have caused severe damage to road facilities such as bridges and embankments, resulting in serious traffic delay in some cases. In the case of the 1995 Kobe Earthquake, traffic congestion in Kobe- and Osaka areas lasted for months due to severely damaged road and emergency response was disturbed. After the Kobe Earthquake, seismic performance to be secured for road facilities was reviewed. Retrofitting projects have been promoted to mitigate the loss for future earthquakes in Japan. Meanwhile, road managers have been requested to fulfill the responsibility to explain efficiency of road projects. In order to meet the necessity, National Institute for Land and Infrastructure Management has been developing practical cost benefit assessment procedure for road earthquake disaster prevention projects. In the procedure, various earthquake-induced losses, such as physical loss to road facilities, loss of casualties due to bridge collapse and detour loss resulting from disrupted road network, are evaluated on monetary basis.

The cost benefit assessment procedure is applied to a case study for a three-year retrofitting program in Tokyo and the surrounding area. The loss reduction expected to be realized from the program is regarded as the benefit from the program and compared with cost of the program operation. Applicability of the cost benefit assessment procedure is discussed.

1. INTRODUCTION

After the 1995 Kobe Earthquake, seismic performance secured for road facilities was reviewed and retrofitting programs have been steadily implemented. Meanwhile, road managers have been requested to fulfill the responsibility to explain efficiency of road projects. However, in the present cost benefit analysis for road projects in Japan, benefit acquired from projects are evaluated on monetary basis in terms of reduction in travel time, travel cost and traffic accident, though various kinds of benefit can be obtained from the road projects including disaster prevention projects. National Institute for Land and Infrastructure Management has been developing the cost benefit assessment procedure for earthquake disaster prevention projects. [1][2] The procedure proposed in this paper comprises 3 steps; seismic hazard analysis, vulnerability assessment for bridges and embankments, and cost-benefit assessment for retrofitting or new road construction. In the seismic hazard analysis, authors propose a simplified procedure to consider all the potentially damaging earthquakes around the study area. In the vulnerability assessment, practical procedures to estimate damage to road facilities are employed. In the cost-benefit assessment, various factors for benefit assessment are organized in terms of difficulty in quantitative assessment, magnitude of the estimated loss and applicability for

practical use. In this paper three factors are chosen for case study and their assessment processes are described. They are direct loss to road facilities, loss of casualties due to facility failure and detour loss caused by disrupted road network. Benefit assessment processes for the other factors are detailed in Kusakabe et al. (2004). [1]

In order to face the necessity to retrofit all the bridges vulnerable to strong ground motions comparable to the Kobe Earthquake, three-year retrofitting program was implemented intensively from 2005. In the retrofitting program, bridges designed in accordance with the standards earlier than 1980 Road Bridge Guidelines were retrofitted since the bridges designed on the basis of the subsequent standards didn't suffer severe damage in the Kobe Earthquake. In this paper, the proposed cost benefit assessment procedure is applied to the three-year retrofitting program. The assessment case study is conducted for Tokyo and the surrounding area. Based on the case study applicability of the cost benefit assessment procedure is discussed.

2. COST BENEFIT ASSESSMENT PROCEDURE

Figure 1 shows flow chart for the proposed cost benefit assessment procedure. The assessment consists of three steps mentioned above, i.e. seismic hazard analysis, vulnerability assessment for road facilities and cost-benefit assessment for retrofitting or new road construction. In cost-benefit assessment, loss estimations are carried out for road networks before and after earthquake disaster mitigation projects. The loss reduction derived from the project implementation is regarded as the benefit and compared with cost of the projects. The assessment procedure for each step is described in the following.

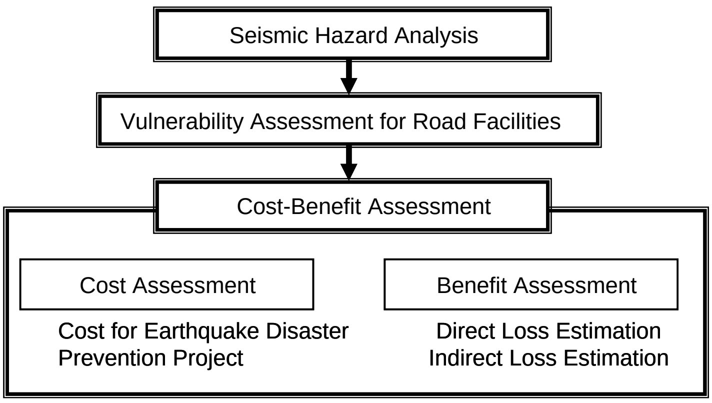

Figure 1. Flow Chart for Cost Benefit Assessment

2.1 Seismic Hazard Analysis

All the earthquakes which potentially cause damages to road facilities can be considered in seismic hazard analysis. [3] In the case earthquake disaster prevention program should be intensively implemented with special focus on a certain particular earthquake with the greatest impact on the study site, only the earthquake can be chosen in the analysis. Ground motion intensities are estimated at road facility sites based on attenuation relationship, e.g. Kataoka et al.(2006). [4] Seismic source models considered in seismic hazard analysis consist of active faults, subduction zones and background zones. Earthquakes are assumed to occur repeatedly on active faults and subduction zones with particular magnitudes and recurrence intervals. Earthquakes from unspecified sources, e.g. blind thrust faults, are assumed to occur randomly in time and space within background zones. Based on historical earthquake records, earthquake occurrence rate and magnitude-frequency relationship within each background zone are evaluated and assumed to be uniform in the zone. In the case

occurrence time for previous event is known for the earthquakes on active faults and subduction zones, time-dependent stochastic process model is employed for evaluating earthquake occurrence rates. In the case occurrence time for previous event is unknown, stationary Poisson process is employed for the earthquake occurrence. Simplified way to consider many earthquakes is described in 2.3.4.

2.2 Vulnerability Assessment for Road Facilities

Practical vulnerability assessment procedures are applied to damage estimation for bridges and embankments. Based on road facility data readily available and ground motion intensities estimated at the facility sites, damage to bridges and embankments can be estimated in the procedures.

2.2.1 Bridges

In accordance with the lessons learned from the Kobe Earthquake, practical procedure to estimate damage to bridges is proposed by Kobayashi et al (2005). [5] The damage to bridges can be estimated based on ground motion intensities at the sites and fundamental property data for the bridges such as built year and structural type. The estimated damage is classified into three levels shown in Table 1 below.

Table 1. Damage Level of Bridges

Damage Level	Damage State
A(Serious)	Bridge suffers damage seriously affecting capacity for load bearing. Bridge can suffer critical damage such as collapse.
B(Medium)	Though bridge suffers damage affecting capacity for load bearing, urgent use is possible unless the damage state gets serious by aftershocks and live loads.
C(Minor)	No influence on load bearing capacity

2.2.2 Embankments

Road facility inspection guidelines for disaster prevention [6] are prepared in order to evaluate and consider the vulnerable status of facilities in road management. The inspected status has been compiled into a database. Practical procedure to estimate damage to embankments is proposed by Public Works Research Institute (2003). [7] Based on ground motion intensities at the sites and the inspected status above, settlement of embankment can be estimated. Damage states of embankments are classified into two categories as in Table 2.

Table 2. Damage Level of Embankments

Damage Level	Damage State
A(Serious)	Estimated settlement is larger than or equal to 1m.
C(Minor)	Estimated settlement is smaller than 1m.

2.3 Cost-Benefit Assessment

Assessment factors for various kinds of losses induced by earthquake road disasters are shown in Table 3. The assessment factors are classified into “direct loss” and “indirect loss”. Table 3 also shows difficulty in monetary quantification, magnitude of estimated loss and applicability for practical assessment. Based on the table, three assessment factors with high applicability are chosen for a case study described afterward; direct loss of road facilities, loss of casualties caused by damage to road facilities, and detour loss caused by disrupted road function. Assessment processes for the three factors are described below. The other factors with medium applicability are desirable to consider in loss assessment if feasible. Assessment processes for these factors are detailed in Kusakabe et al.(2004). [1]

Table 3. Factors for Loss Assessment

Loss Factors				Difficulty in Monetary Quantification	Magnitude of Estimated Loss	Applicability for Practical Assessment	Content of factors
Direct Loss	Physical Loss of Road Facilities			Intermediate	Medium	High	Recovery cost for damaged facilities
	Physical Loss Caused by Road Facility Failure	Physical Loss of Train tracks and casualties		Difficult	Great	Medium	Loss of train tracks and casualties caused by bridge failure. If all the data necessary to evaluate the factor(e.g. train track info and number of passengers) are available, it should be considered.
		Physical Loss of Lifeline Attached to Bridges		Intermediate	Small	Medium	Loss of physical damage to ductworks attached to bridges. Though it might be difficult to assume damage to ductworks considering damage state of the bridges and ductwork installation locations, the factor should be taken into consideration if feasible.
	Loss of Casualties Caused by Damage to Road Facilities			Intermediate	Great	High	The casualties consist of road users driving on or under collapsed bridges at times of earthquakes.
Indirect Loss	Loss Caused by Disrupted Road Functionality	Interruption for Non-Emergency Activities(Vehicles)	Detour Loss	Intermediate	Great	High	Increase in travel- time and cost caused by road network disruption.
			Travel Cancelling	Intermediate	Great	Low	Loss of travel cancellation. At this point, It is difficult to estimate post-earthquake traffic demand.
			Public Service Disruption	Difficult	Small	Low	Loss caused by disruption of public services such as garbage collections. At this point, this factor is difficult to consider.
			Increase in Traffic Accidents	Difficult	Small	Low	Loss due to traffic accidents which is attributed to road facility failure. It is difficult to evaluate the dependency of accidents on road facility failure.
			Deterioration of Residential Environment	Difficult	Small	Low	Loss caused by decreased comfort in daily life. At this point, it is difficult to consider this factor.
		Interruption for Emergency Activities	Fire Engines	Intermediate	Medium	Medium	Fire loss due to delay of fire engines. If necessary, the factor should be considered, though flame propagation simulation needs to be implemented.
			Rescue Vehicles and Ambulances	Intermediate	Medium	Medium	Loss of fatalities caused by delay of emergency vehicles.
			Vehicles for Restoration Work	Difficult	Great	Low	Loss caused by delay of recovery work. Since recovery work is different from facility to facility, it is difficult to apply consistent assessment.
			Transit Vehicle for Critical Materials	Difficult	Small	Low	Loss caused by delayed transit. Basic units for travel time and travel cost are difficult to be assumed objectively.
			Evacuation Vehicles	Difficult	Small	Low	Loss caused by delayed evacuation. Basic units for travel time and travel cost are difficult to be assumed objectively.
	Interdependent Disturbance	Railroad Traffic under Overpasses		Intermediate	Great	Medium	Loss suffered by railroad users and railroad companies. If all the data necessary to evaluate the factor are available, it should be considered.
		Disfunction of Lifeline Attached to Bridges		Intermediate	Great	Medium	Loss suffered by lifeline users and lifeline companies. If all the data necessary to evaluate the factor are available, it should be considered.
	Natural Environmental Deterioration			Difficult	Small	Low	Loss due to natural environmental deterioration caused by various inconveniences such as traffic congestion. Since it is difficult to evaluate the effects of road disruption on natural environment, the factor is not considered at this point.

2.3.1 Direct Loss of Road Facilities

Direct loss of road facilities ($l_{facility}$) corresponds to recovery cost for damaged facilities. Recovery cost is evaluated depending on damage state of the road facility. Tables 4 and 5 show an example of recovery cost for a bridge and that for embankment, respectively. The recovery costs employed in the subsequent case study are computed on the assumption that general recovery- and retrofitting constructions are applied to damaged facilities.

Table 4. Recovery Cost for Bridge

Damage Level	Restoration Cost (thousand yen/1000m^2)	Retrofitting Cost (thousand yen)	Summary of Recovery Content
A	190,700	-	Removal and Reconstruction
B	2,500	25,000	Repair and Retrofitting
C	-	-	No Necessity to Repair

Recovery cost for Three-span Continuous Viaduct (length: 150m, width: 10.7m, number of lanes: 4)

Table 5. Recovery Cost for Embankment

Damage Level	Restoration Cost (thousand yen/1000m^2)	Summary of Recovery Content
A	6,200	Removal and Reconstruction
C	-	No Necessity to Repair

Recovery cost for embankment (height:10m, crown width:14m, length:150m)

2.3.2 Loss of Casualties

Loss of casualties attributed to failure of road facilities is evaluated. The casualties are classified into two kinds; road users driving on collapsed bridges at times of earthquakes and those driving directly under collapsed overpasses. The loss of casualties is evaluated according to the Equation (1).

$$l_{casualty} = N_{user} \times \sum_i (R_L^i \times E_{casualty}^i) \qquad (1)$$

where,

$l_{casualty}$: Loss of Casualties

N_{user} : Number of road users driving on or under collapsed bridges at times of earthquakes

R_L^i : Loss ratio for each casualty status i

$E_{casualty}^i$: Monetary expense for each casualty status i

i : Casualty status (fatality, serious Injury, light injury)

Number of road users driving on or under collapsed bridges at times of earthquakes (N_{user}) is estimated from traffic volume. The loss ratio R_L^i in Equation 1 stands for the possibility that road users driving on or under the collapsed bridges suffer either one of the three casualty status; fatality, serious injury and light injury. The loss ratio R_L^i employed in this paper is shown in Table 6. R_L^i is empirically derived from case examples in the Kobe Earthquake. [8] Loss ratio R_L^i for road users driving under collapsed bridges is assumed to be 100% for fatality and 0% for the others. Loss for each casualty status ($E_{casualty}^i$) is computed as the summation of human loss and business owner's loss shown in Table 7.

Table 6. Loss Ratio for Each Casualty Status (Road User Driving on Collapsed Bridges)

Casualty	Serious Injury	Light Injury
3%	6%	9%

Table 7. Human- and Operating Body Loss per Casualty (Thousand Yen)

Status	Human Loss	Operating Body Loss
Fatality	33,515	807
Serious Injury	11,517	212
Light Injury	652	50

2.3.3 Detour Loss

Detour loss corresponds to the travel cost increment caused by detour and traffic congestion. In order to evaluate the detour loss, travel costs are evaluated for study road network with and without estimated damages to road facilities. Detour loss is defined as Equation (2).

$$l_{detour} = C_{after} - C_{before} \qquad (2)$$

where,

l_{detour} : Detour Loss

C_{after} : Travel cost for road network with estimated damages

C_{before} : Travel cost for road network without estimated damages

Travel cost comprises monetary value of travel time and expense for travelling. Monetary value of travel time and necessary expense for travelling are computed according to the Cost Benefit Analysis Manual (MLIT, 2003). [9] In the present paper traffic demand for various sets of origin and destination under non-emergency condition is applied to post-earthquake traffic assignment since post-earthquake traffic

demands is difficult to be estimated at this point. Authors assume that various activities, such as economic activities and commuting, recover without long passage of time from wide area viewpoint. This assumption can not be applied to severely afflicted areas or disrupted traffic condition immediately after damaging earthquakes. Post-earthquake traffic demand and traffic condition should be considered especially in the case assessment targets are also set on emergency activities and socioeconomic activities in severely afflicted area.

Traffic regulations are enforced at damaged facility sites. Based on the actual traffic regulations in the 1995 Kobe Earthquake and the Mid Niigata Prefecture Earthquake in 2004, periods of time for traffic regulation are assumed to vary depending on kinds of road managers and damage level of road facilities as shown in the Table 8. Note that traffic regulations are mostly categorized in two types; traffic regulation for one side way and that for both ways. Assuming that 2 day traffic regulation for one side way rates as 1 day regulation for both ways, actually experienced periods of time for one side regulation are converted into those for both side regulations. Table 8 shows the average period of time for both side traffic regulation. In order to simplify the assumption for traffic regulations, authors assume both side regulations are enforced at all the damaged facility sites and the average period of time for both side regulation can be applied to them.

Table 8. Average Period of Time Under Traffic Regulation

	Damage Level	Facility Manager	Period of Time for Traffic Regulation (days)
Bridge	A	National Government	75
		Prefectural Government	300
	B	Common	4
	C	Common	-
Overpass	A	Common	7
Embankment	A	National Government	7
		Prefectural Government	300
	C	Common	-

2.3.4 Computational Simplification

The assessment of detour loss can be costly computation especially in the case the detour loss needs to be evaluated for all the damaging earthquakes around target area. The number of earthquakes to be considered for detour loss assessment might be reduced according to the following simplification.

(A) Study area is divided into several grid zones as shown in Figure 2.
(B) Direct loss of road facilities ($l^i_{facility}$) is estimated for each earthquake i. Expected direct loss for each earthquake is evaluated by multiplying the earthquake occurrence rate and the estimated direct loss of road facilities.
(C) The earthquake which causes the greatest “expected direct loss” in each grid zone is chosen as a representative event of the grid zone. $L_{facility}$ stands for the direct loss caused by the chosen earthquake.
(D) Loss of casualties $L_{casualty}$ and detour loss L_{detour} are evaluated for the earthquakes chosen in (C).
(E) Loss of casualties $l^i_{casualty}$ and detour loss l^i_{detour} for all the other earthquakes are evaluated in Equations (3).

$$l^i_{casualty} = L_{casualty} \times l^i_{facility} / L_{facility} \quad (3)\text{-}1$$

$$l^i_{detour} = L_{detour} \times l^i_{facility} / L_{facility} \quad (3)\text{-}2$$

where,

$l^i_{casualty}$: Loss of casualties for each earthquake i

$L_{casualty}$: Loss of casualties caused by the earthquake chosen in (C)

$l^i_{facility}$: Loss of facility caused by each earthquake i

$L_{facility}$: Loss of facility caused by the earthquake chosen in (C)

l^i_{detour} : Detour loss caused by each earthquake i

L_{detour} : Detour loss caused by the earthquake chosen in (C)

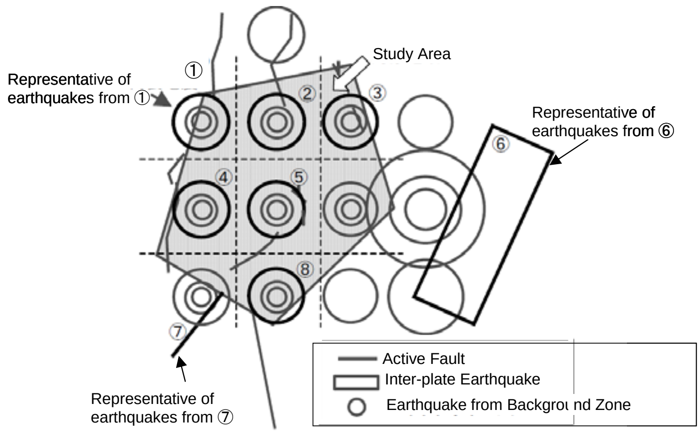

Figure 2. Seismic Sources

2.3.5 Expected Loss Reduction

Expected loss reduction R_L corresponds to the benefit expected to be obtained from retrofitting or new road construction. R_L is estimated according to Equation (4).

$$R_L = \sum_i (l_i^{before} - l_i^{after}) \times P_i \qquad (4)$$

where,

R_L : Expected loss reduction acquired from earthquake disaster prevention project

l_i^{before} : i -th earthquake-induced loss ($l_{facility} + l_{casualty} + l_{detour}$) for road network without project implementation

l_i^{after} : i -th earthquake-induced loss ($l_{facility} + l_{casualty} + l_{detour}$) for road network which has already undergone project implementation

P_i : Occurrence rate of i -th earthquake

2.4 Cost-Benefit Assessment

Benefit (expected loss reduction R_L) is estimated according to 2.3.5. Also, cost for road disaster prevention projects, such as retrofitting and new road construction, are computed. As shown in Equations (5), total benefit B_{total} and total cost C_{total} are evaluated by summing up all the cost c_i and benefit b_i in each fiscal year through assessment period of time. The assessment period of time $S_b + N$ is set to 50 years based on the average service period of time for road facilities. Social discount ratio r is set to 4% according to Technical Guidance on Cost Benefit Analysis for Public Project Evaluation (MLIT, 2004). [10] Cost Benefit ratio is derived in Equation (6).

$$B_{total} = \sum_{i=0}^{Sb+N-1} b_i / (1+r)^i \qquad (5)\text{-}1$$

$$C_{total} = \sum_{i=0}^{S_C-1} c_i / (1+r)^i \qquad (5)\text{-}2$$

where,

b_i : Benefit obtained in i -th year

S_b : Period of time for project implementation

$S_b + N$: Assessment period of time

r : Social discount ratio

c_i : Project cost in i -th year

S_c : Period of time necessary to complete project

$$R_{B/C} = B_{total} / C_{total} \tag{6}$$

where,

$R_{B/C}$: Cost-benefit ratio

B_{total} : Total benefit acquired through assessment period of time

C_{total} : Total cost for earthquake disaster prevention project

3. CASE STUDY FOR TOKYO METROPOLITAN AREA

The cost benefit assessment procedure is applied to retrofitting program implemented in Tokyo and the surrounding area. Figure 3 shows the road network employed for the case study. The road network consists of the roads below.

- Roads administrated by Ministry of Land, Infrastructure and Transport
- Roads administrated by Metropolitan- and prefectural governments
- Roads administrated by government-designated cities

There are 5,996 bridges on the road network. Red dots stand for target bridges for retrofitting. The target bridges account for 678 (11%) of all the bridges.

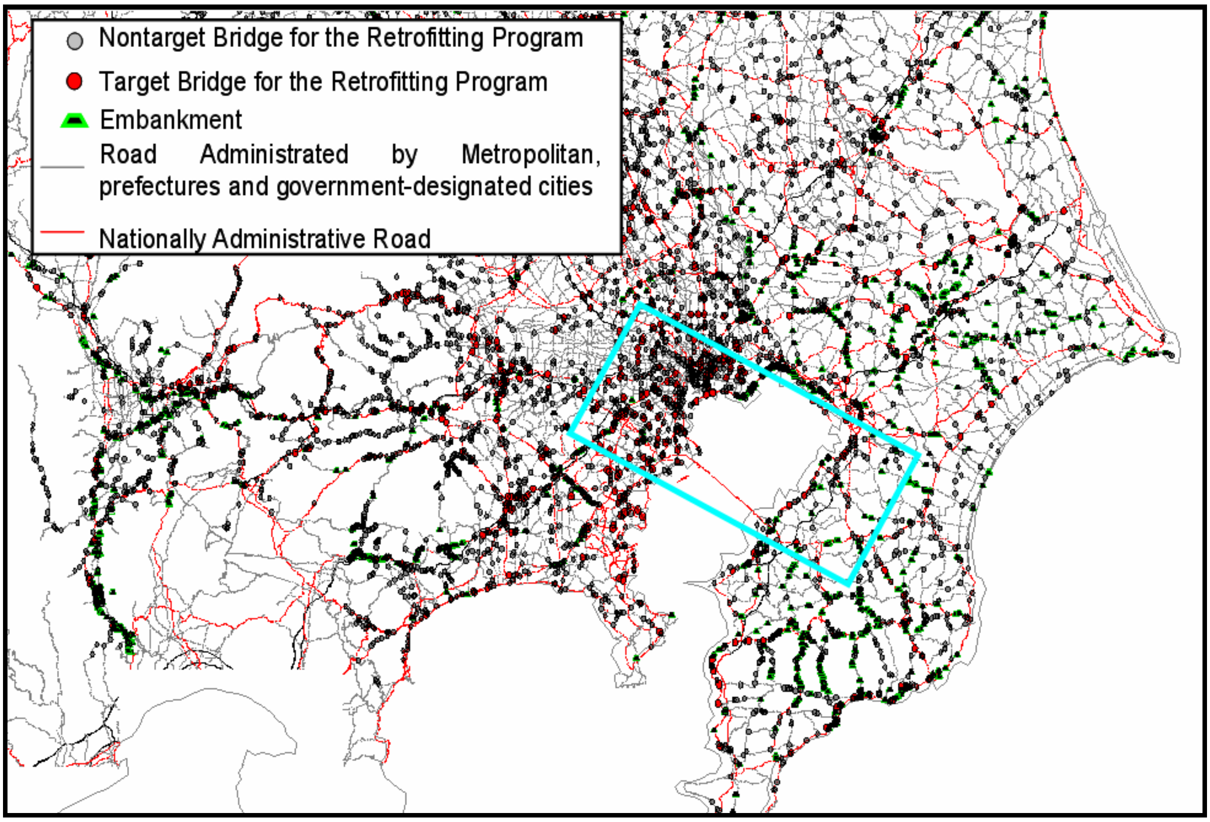

Figure 3. Road Network for Case Study

The case study focuses on just one earthquake; The Northern Tokyo Bay Earthquake(Mj7.3), which is one of large-scale scenario events in this area and employed for damage estimation by Central Disaster Management Council. Based on the historical earthquake records, average recurrence interval for the Northern Tokyo Bay Earthquake is assumed to be 23.8 years. The source location is also shown in Figure 3.

3.1 Seismic Hazard Analysis and Vulnerability Assessment for Road Facilities

Estimated damage states of bridges and embankments are shown in Table 9. The table indicates the number of bridges suffering damage A and B decreases by retrofitting. The time periods necessary for facility restoration are also estimated. The period of time to enforce traffic regulation declines by 24,799 days through retrofitting. The time reduction accounts for about 37 days per bridge.

Table 9. Damage to Road Facilities

State of Retrofitting	Bridge			Embankment	
	A	B	C	A	C
Before Retrofitting	373	2,970	2,653	4	880
After Retrofitting	244	2,564	3,188		

3.2 Benefit Assessment

Loss of road facilities, loss of casualties and detour loss are evaluated according to the procedure shown in 2. Table 10 shows the evaluated loss and loss reduction obtained through retrofitting. The loss reduction accounts for 1,538 billion yen.

Table 10. Loss Assessment

		Loss (Billion Yen)		Loss Reduction (Billion Yen)
		Before Retrofitting	After Retrofitting	
Direct Loss	Loss of Facilities	288	180	108
	Loss of Casualties	12	6	5
Indirect Loss (Detour Loss)		4,407	2,983	1,425
Total		4,707	3,169	1,538

3.3 Cost Benefit Analysis

Table 11 shows the cost and benefit through the assessment period of time. Social discount ratio is set to 4% in the case study. The cost is estimated only for the first three years since the retrofitting program is completed in three years. The total cost is estimated at 84 billion yen. Benefit is estimated on the assumption that full effect of retrofitting program comes out three years later from the beginning of the program. Table 11 shows the benefit and cost for each year. The benefits (pure value) shown in the table are derived by multiplying each year benefit with earthquake occurrence rate. As a result, total benefit accounts for 538 billion yen. Based on the estimated total cost and benefit, benefit-cost ratio is estimated to reach about 6.4.

Table 11. Cost and Benefit Assessments

Elapsed Years i	$1/(1+r)^i$	Benefit (Billion Yen)		Cost (Billion Yen)	
		Pure Value	Present Value	Pure Value	Present Value
1	1	0	0	29	29
2	0.96	513	492	29	27
3	0.92	1,146	945	29	26
4	0.88	1,538	1,361	0	0
5	0.85	1,538	1,306	0	0
6	0.82	1,538	1,254	0	0
⋮					
46	0.16	1,538	245	0	0
47	0.15	1,538	235	0	0
48	0.15	1,538	226	0	0
49	0.14	1,538	217	0	0
50	0.14	1,538	208	0	0
Total			30,462		84
Total Benefit $B_{total} = 30{,}462 \times 0.883/50 = 538$				Total Cost $C_{total} = 84$	

3.4 Computational Issues

Traffic assignment needs to be implemented for disrupted road network since post-earthquake traffic flow is necessary for detour loss assessment. At this point, non-variable traffic demand model is employed in ordinary cost benefit analysis for road projects in Japan. The non-variable demand model is also employed in the case study so that the applicability of the popular traffic assignment can be studied.

Road links corresponding to the disrupted sections need to be disconnected in the traffic assignment. However, in the case that origins or destinations are isolated, the traffic assignment is not progressed. This is because any traffic volume can not be allocated to the disrupted sections and at the same time traffic demand can not be reduced. Therefore, extremely slow travel velocity, 0.1 km/h, is assumed for the disrupted road links in this study. Resultant traffic assignment for damaged road network without retrofitting is shown in Figure 4. All the colored links other than black links indicate the disrupted road sections. The blue links correspond to disrupted road sections without any assigned traffic volume. The green links with and without red colored borders stand for the road sections to which a certain amount of traffic volume is assigned against the fact the sections are disrupted. The reason traffic volumes are assigned to the green lines with red colored borders is there is no detour route. The green links with red colored borders account for 559 links, which corresponds to about 10% of all the road links. The reason traffic volumes are assigned to the green links without red borders is the detour distances are long. Those links account for 332 links, which corresponds to about 5% of all the road links.

Assuming slow travel velocity for disrupted road links, traffic volumes are assigned to actually disrupted road links. Travel cost increment additionally caused by the assumption substitutes for loss of travel cancelling and long detour loss. In order to simulate actual post-earthquake traffic flow, traffic demands need at least to be adjusted prior to traffic assignment in consideration of post-earthquake road users' behavior, such as travel cancelling and destination change. Surveys of road users' behavior after events (e.g. [11]) are essential for understanding the behavioral change.

It is indicated that variable traffic demand model is superior to non-variable model in terms of

reproducibility of post-earthquake traffic flow. (e.g. [12]) Since traffic demand changes in variable traffic demand model, disrupted road sections can be actually disconnected in traffic assignment. Therefore, the variable demand model enables to directly consider travel cancelling and long detour forced to take by disrupted road, and avoid the computational issues acknowledged in non-variable demand model. However, variable traffic demands for various origins to destinations need to be formulated in order to employ the variable demand model. Surveys of post-earthquake traffic behavior and the data sharing are also essential to making variable traffic demand model for earthquakes.

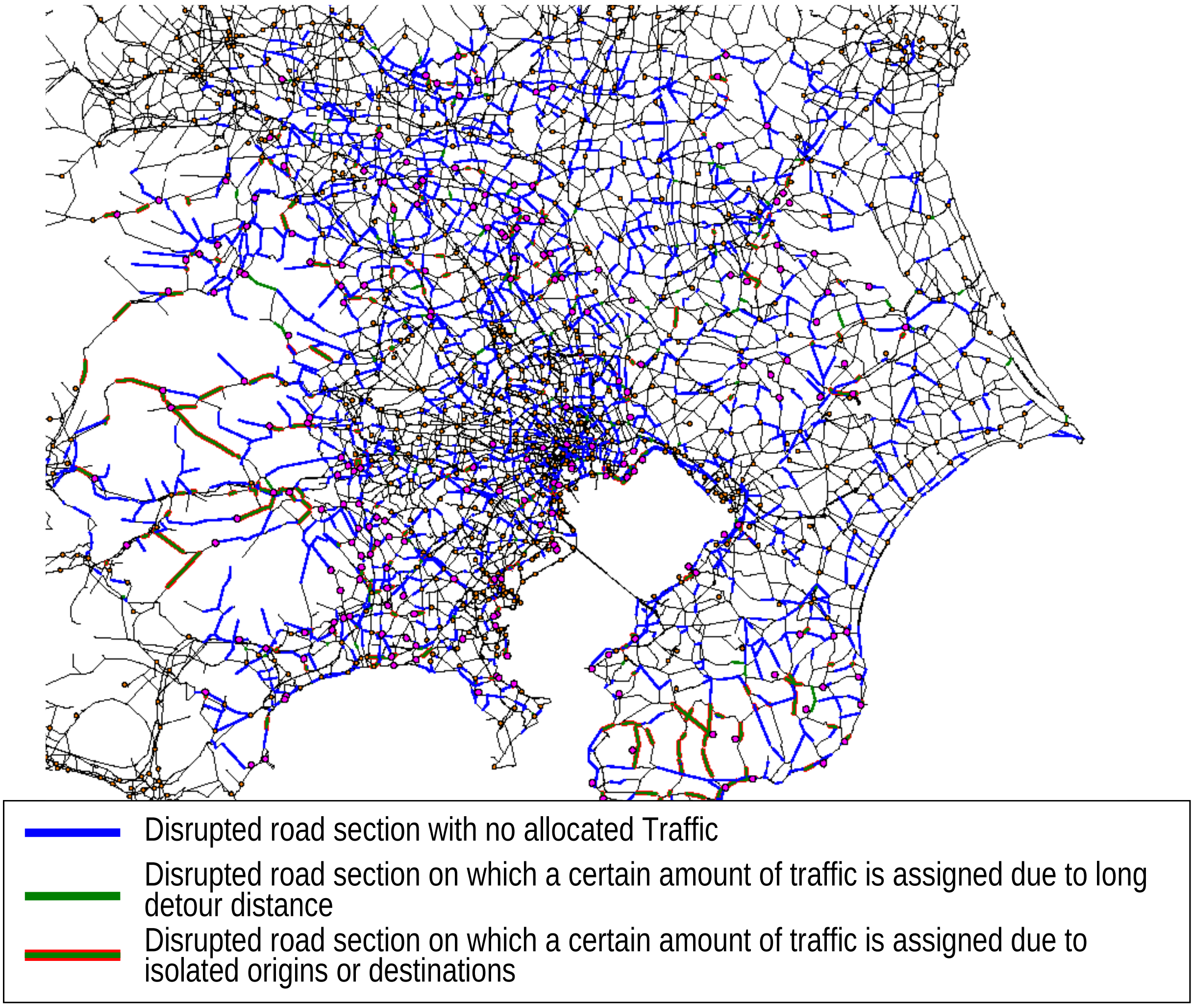

Figure 4. Traffic Allocation (Road without Retrofitting)

4. CONCLUSION

Practical cost benefit assessment procedure is proposed in terms of benefit acquired from earthquake disaster prevention projects. The assessment procedure is applied to retrofitting program in Tokyo and the surrounding area. It is shown that the procedure enables to evaluate benefit-cost ratio for earthquake disaster prevention projects implemented in wide area. Several issues acknowledged in the traffic allocation for post-earthquake road network is also discussed.

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